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DRAWINGS ATTACHED.

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COMPLETE SPECIFICATION.

Improvements in or relating to Polarising Microscopes.

We, NATIONAL RESEARCH DEVELOPMENT CORPORATION, a British Corporation established by Statute of 1 Tilney Street, London, W.1, England, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to polarising microscopes.

According to the invention there is provided a polarising microscope of the kind comprising a light source, a polariser adapted to convert a beam of light from the light source into a beam of plane polarised light, a magnifying lens system and an analyser mounted for rotation about the optical axis of the microscope and adapted, when rotated to a certain position, to prevent passage of a beam of plane polarised light, and characterised by a corrector, consisting of one or more optical elements, located in the path of the beam between the polariser and the analyser, the characteristics of the corrector being such as to produce barrel distortion (as hereinafter defined) of the state of polarisation of the beam to an extent such as substantially to balance pincushion distortion (as hereinafter defined) of the state of polarisation of the said beam caused by optical elements of the microscope other than the corrector whereby in the absence of a specimen in the microscope the light reaching the analyser is a beam of parallel-plane polarised light (as hereinafter defined).

The invention will be more readily understood from the following description relating to Figures 1 to 3 of the drawings accompanying the Provisional Specification and Figure 4 accompanying this Specification, in which:—

Figure 1 is a diagram showing the layout of a normal polarising microscope;

Figure 2 is a diagram showing the layout of one embodiment of the invention;

Figure 3 is a diagram showing the layout of another embodiment of the invention; and

Figure 4 is a perspective view of an optical element forming a corrector or a part thereof.

Corresponding items in these figures are given corresponding reference numerals.

Polarising microscopes are primarily used to discover the path difference between the two components of a beam of plane polarised light, caused by a specimen, from which information of the composition or properties of the specimen can be obtained. A beam of light is passed through a polarising crystal or filter commonly called and herein referred to as a "polariser", through the specimen and then through another polarising crystal or filter, commonly called and herein referred to as an "analyser". The analyser is adjusted by rotation about the optical axis of the microscope so that, in the absence of a specimen, the light of the beam is blacked out due to the plane of polarisation of the analyser being normal to the plane of polarisation of the beam of light reaching it. With the specimen in place a compensator may be operated until the beam is again blacked out and the amount of compensation is a measure of the path difference due to the specimen. The various magnifying lenses of the microscope are inserted at suitable places in the path of the beam.

Figure 1 illustrates a conventional microscope of this type wherein a beam of light 1 from a light source (not shown) is passed through a polariser 2, an iris 3, and a condenser 4, to illuminate a specimen on the slide 5, the light rays then passing through

the microscope objective 6 and an analyser 7.

In use the analyser 7 can be rotated about the optical axis of the instrument and ideally, when there is no specimen on the slide 5, adjustment of analyser 7 enables the light source to be completely extinguished when the direction of polarisation of 7 is exactly perpendicular to that of 2.

In practice, however, when an objective of high numerical aperture is used, some rotation of the plane of polarisation is caused by the various intermediate optical elements, principally condenser 4 and objective 6. This rotation of the plane of polarisation occurs in the oblique quadrants as a result of the greater loss by reflection at the various glass/air surfaces of the tangential as compared with the radial components of the polarised light. When this occurs it is not possible to obtain complete extinction of the light beam passing to the eyepiece (not shown) of the microscope. This may be more readily appreciated by means of the diagrams to the right of Figure 1, in which the plane of polarisation of the light at various positions within the cross-section of the beam is indicated by lines which follow the direction of the electric vector. At any level between the polariser and the condenser, this diagram, (i.e. diagram 8), consists of parallel straight lines crossing the whole area of the beam, indicating that the plane of polarisation is the same everywhere within the beam, a condition which is herein described as " parallel-plane " polarisation. Between the objective and analyser, however, after the state of polarisation has been changed by the process described above, only the line through the centre of the diagram remains straight, each of the others having a curvature, the concavity of which is directed away from the central line and the magnitude of which is roughly proportional to the distance of the line from the central line, as shown in diagram 9. This effect is herein referred to as " pincushion distortion " of the state of polarisation of the beam, since this is the name customarily given to the situation where the image, formed by a lens system, of a set of parallel straight lines, is a set of lines curved in the way just described. Diagram 10 illustrates the resulting incompletely extinguished beam.

It is now proposed to introduce a corrector consisting of one or more optical elements, into the path of the light beam between the polariser and the analyser so as to produce, at each position within a cross-section of the beam, a rotation of the plane of polarisation equal and opposite to the rotation brought about in the manner described above by other elements of the optical system. The characteristics and location of the corrector are such that, in a diagram representing the electric vector in a cross-section of the beam emerging from the corrector the only line to remain straight is the one which passes through the centre of the beam, each of the others having a curvature the concavity of which is directed towards the central line, and the magnitude of which is roughly proportional to its distance from the central line. This effect is herein referred to as " barrel distortion " of the state of polarisation, since this is the name customarily given to the situation where the image, formed by a lens system, of a set of parallel straight lines, is a set of lines curved in the way just described.

Figure 2 illustrates a practical embodiment of the invention. The light from a light source (not shown) first passes through a field iris 11 before passing through the polariser 2. On emerging from polariser 2 the light passes through a corrector consisting first of a slab 12 of birefringent material, the effect of which is to produce elliptical polarisation such that at each point within the beam of light the amplitude of the out-of-phase component is approximately directly proportional to the amount of correctional rotation that is required at that point, in the manner shown in diagram 13. The slab 12 should be of uniaxial birefringent material with the optic axis parallel with the optical axis of the microscope and may consist of a piece of calcite or two superimposed pieces of quartz of equal thickness one right-handed and the other left-handed. The corrector further comprises a quarter-wave plate 14 placed in the path of the beam, which converts the polarisation pattern 13 to the pattern shown in diagram 15 by conversion of the ellipticity of polarisation to rotation of polarisation. The quarter-wave plate brings the out-of-phase component of the elliptically polarised light into phase with the main component so that the resultant is plane polarised light with its direction of polarisation rotated through the required amount and it will be noted that this is complementary to diagram 9 in Figure 1, so that when the beam has further been distorted by passing through elements 4, 5 and 6, the beam is restored to parallel-plane polarisation, as illustrated in diagram 16 which resembles diagram 8.

It is then possible by adjustment of analyser 7 to extinguish the whole of the light beam as indicated by diagram 17.

In another embodiment of the invention shown in Figure 3 the effect obtained by items 12 and 14 of Figure 2 is obtained by a corrector consisting of a single half-wave plate 18. This half-wave plate must be composed of a biaxial birefringent material with refractive index in the direction parallel to the optical axis of the instrument which differs considerably from the refractive indices in directions parallel to the plate which latter must not greatly differ from one another. Mica is a suitable material of this

kind and should be used with the plane of cleavage normal to the optical axis of the instrument.

To achieve the same effect as the embodiment described in relation to Figure 2, however, it may be necessary for the angle of divergence of the light emerging from the field iris 11 to be greater than in the case of the Figure 2 embodiment, but this presents no particular difficulty.

Figure 4 shows another form which the corrector may take. It consists of a plate of optically active material that is to say a material which rotates the plane of polarisation. The thickness of the plate is not uniform over its area but at each point through which the beam passes the thickness is such that, due to rotation of the plane of polarisation, it is distorted in barrel distortion manner. There is of course an overall rotation of the plane of polarisation which may be corrected by passing the beam through an additional sheet of the optically active material which rotates the plane of polarisation in the opposite direction and whose faces are plane, parallel to one another and normal to the optical axis of the microscope.

The optical element 19 shown in Figure 4, which is drawn in the attitude appropriate to a laevo-rotary material has an upper face 20 of convex part-cylindrical form and a lower face 21 of concave part cylindrical form the radii of the two cylinders being equal and the axes thereof being at right-angles to one another. These two axes are disposed at 45° to the plane of polarisation of the light where it passes through the specimen, which is indicated by the dotted line 22. The element 19 is relatively thin in two diametrically opposite quadrants 23 and 24 and relatively thick in two diametrically opposite quadrants 25 and 26. Along the plane of polarisation indicated by the line 22 the thickness is uniform and a section along the plane of polarisation would expose a face bounded by parallel upwardly curved dotted lines 27 and 28. The rotation of the plane of polarisation along the line of this section is uniform and is cancelled either by the said additional sheet of optically active material or, alternatively, by rotation of the polariser. The central line in a diagram such as Figure 8 would be rotated but would remain straight. Lines in the lower right-hand and upper left-hand quadrants would be rotated less than along the central line and lines in the upper right-hand and lower left-hand quadrants would be rotated more than along the central line, producing the condition of barrel distortion illustrated in diagram 15 of Figure 2.

As another alternative the corrector may comprise a piece of uniaxial birefringent material, shaped as shown in Figure 4 with the optic axis perpendicular to the axis of the microscope and at 45° to the plane of polarisation of the rays emerging from the polariser, that is to say along the line 25, 26 or the line 23, 24, followed by a plane parallel plate of uniaxial birefringent material having such a thickness and being so oriented as to introduce a path difference equal to but in the opposite direction from that of the centre of the shaped plate. As the path difference of the plane parallel plate is uniform over the whole area of the beam the result is to annul the ellipticity both at the centre of the beam and along the diameters of the beam where the shaped plate is of uniform thickness, i.e. along the diameter 22 of Figure 4 and along the diameter at right angles thereto. These elements will produce elliptical polarisation of the rays as shown in diagram 13 of Figure 2 instead of the rotation produced by the optically active element 19 of Figure 4. The corrector, in this case, further comprises a quarter-wave plate such as 14 of Figure 2, by which the residual elliptical polarisation is converted into barrel distortion in the same manner as described in relation to Figure 2.

In the case where the beam is strongly convergent or divergent at a point convenient for insertion of the corrector this may consist of a half-wave plate of uniaxial birefringent material which alone produces the required barrel distortion by virtue of the different angles at which the light passes through the plate. The slow direction of the half-wave plate may be either parallel to or perpendicular to the plane of polarisation of the light leaving the polariser. Such a plate may, for instance, be incorporated into a condenser lens assembly.

Where, by the use of lenses for instance, the light beam reaching the polariser is strongly divergent or convergent (in which case the polariser will need to be of the polarising filter type and not for example a Nicol prism). The corrector may consist of a lens or lenses to render the beam nearly parallel followed by a half-wave plate with either its fast or its slow direction parallel to the plane of polarisation at the centre of the beam. In this arrangement the light incident on the half-wave plate is characterised by pincushion distortion which is converted to barrel distortion by the half-wave plate.

Where the light beam reaching the polariser is not strongly divergent or convergent as described in the preceding paragraph the corrector may comprise a half-wave plate as described in the preceding paragraph and also lenses between the half-wave plate and the polariser. These lenses, which may be thin concavo-convex lenses of zero power must be chosen so as to introduce an appropriate degree of pincushion distortion of the state of polarisation of the beam, in the same way as described in connection with elements

4, 5 and 6 of Figure 1. This is converted to barrel distortion by the half-wave plate in the same way as described in the immediately preceding paragraph.

It is of course necessary to adjust the corrector by choice of material, dimensions, shape, divergence or convergence of the beam as the case may be, so that the degree of barrel distortion produced thereby is such as to cancel the pincushion distortion introduced into the state of polarisation of the beam by the other elements of the microscope, which will vary as between different types of microscope.

WHAT WE CLAIM IS:—

1. A polarising microscope of the kind comprising a light source, a polariser, a magnifying lens system and an analyser mounted for rotation about the optical axis of the microscope and adapted, when rotated to a certain position, to prevent passage of a beam of plane polarised light and characterised by a corrector, consisting of one or more optical elements, located in the path of the light beam between the polariser and the analyser the characteristics of the corrector being such as to produce barrel distortion, as hereinbefore defined, of the state of polarisation of the beam to an extent such as substantially to balance pincushion distortion, as hereinbefore defined, of the state of polarisation of the said beam caused by optical elements of the microscope other than the corrector, whereby, in the absence of a specimen in the microscope the light reaching the analyser is a beam of parallel-plane polarised light, as hereinbefore defined.

2. A microscope as claimed in Claim 1 wherein the corrector consists of a plate of uniaxial birefringent material with its optic axis parallel with the optical axis of the microscope and a quarter-wave plate, the correcor being located at a position in the beam where the light rays are at least slightly convergent or divergent.

3. A microscope as claimed in Claim 1 wherein the corrector consists of a half-wave plate of biaxial material of which maximum and minimum refractive indices for light polarised with its electric vector in the plane of the plate differ only slightly from one another but differ considerably from the refractive index for light of which the electric vector is perpendicular to the plane of the plate, the corrector being placed in the path of the light beam where the said beam is moderately convergent or divergent.

4. A microscope as claimed in Claim 3 in which the said half-wave plate is of mica with the plane of cleavage normal to the optical axis of the microscope.

5. A microscope as claimed in Claim 1 in which the corrector consists of a half-wave plate of uniaxial birefringent material, oriented with either its fast or its slow direction parallel to the plane of polarisation of the light leaving the polariser, the corrector being placed in the path of the light beam where the said beam is strongly convergent or divergent.

6. A microscope as claimed in Claim 1 with a lens or lenses placed between the light source and the polariser to render the light beam strongly divergent or convergent where it passes through the polariser and in which the corrector comprises a lens to render the beam nearly parallel, followed by a half-wave plate with either its fast or its slow direction parallel to the plane of polarisation at the centre of the beam.

7. A microscope as claimed in Claim 1 in which the corrector consists of a lens or lenses such as to introduce pincushion distortion of the state of polarisation of the beam from the polariser followed by a half-wave plate with either its fast or its slow direction parallel to the plane of polarisation at the centre of the beam.

8. A microscope as claimed in Claim 1 in which the corrector comprises a plate of optically active material whose thickness is not uniform but varies in such a way that the amount of rotation of the plane of polarisation of the beam on passage through the said plate, is such, at each point within the beam as to produce barrel distortion of the state of polarisation of the beam to the extent specified in Claim 1.

9. A microscope as claimed in Claim 8 in which the corrector also comprises a second plate or optically active material the faces of which are plane parallel and perpendicular to the optical axis of the microscope and the direction of rotation and thickness of which is such as to annul any net rotation of the plane of polarisation at the centre of the beam due to the said plate of non-uniform thickness.

10. A microscope as claimed in Claim 8 or Claim 9 in which the said plate of non-uniform thickness has one surface of convex part-cylindrical form and the other surface of concave part-cylindrical form the axes of the two cylinders of which the said surfaces form parts being perpendicular to one another and oriented at 45° to the plane of polarisation of the beam of light where it passes through the specimen, the radii of the said two cylinders being equal.

11. A microscope as claimed in Claim 1 in which the corrector consists of a plate of uniaxially birefringent material with the optic axis perpendicular to the optical axis of the microscope and at 45° to the original plane of polarisation of the beam impinging on the plate, the said plate being of non-uniform thickness such that along a diameter of the said beam at 45° to the said original plane of polarisation the thickness of the plate

increases from the centre to the edges of the plate and along another diameter at right-angles to the first-named diameter the thickness decreases from the centre to the edges of the plate the surfaces of the plate being such as to present a smooth transition of thickness around each circumferential section of the plate between the two said diameters, the corrector further consisting of a plane parallel plate of uniaxial birefringent material.

12. A microscope as claimed in Claim 11 in which the said plate of non-uniform thickness has one surface of convex part-cylindrical form and the other surface of concave part-cylindrical form the axes of the cylinders of which the said surfaces form parts, being perpendicular to one another and oriented at 45° to the plane of polarisation of the beam of light impinging upon the said plate of non-uniform thickness.

13. A polarising microscope substantially as described with reference to Figure 2 of the dawings accompanying the Provisional Specification.

14. A polarising microscope substantially as described with reference to Figure 3 of the drawings accompanying the Provisional Specification.

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PROVISIONAL SPECIFICATION.

Improvements in or relating to Polarising Microscopes.

We, NATIONAL RESEARCH DEVELOPMENT CORPORATION, a British Corporation of 1 Tilney Street, London, W.1, do hereby declare this invention to be described in the following statement:—

This invention relates to polarising microscopes.

The nature of the invention will be more readily understood from the following description relating to the accompanying drawings of which

Figure 1 is a diagram showing the layout of a normal polarising microscope;

Figure 2 is a diagram showing the layout of one embodiment of the invention; and

Figure 3 is a diagram showing the layout of a second embodiment of the invention. Corresponding items in the three figures are given corresponding reference numerals.

In Figure 1 a beam of light 1 from a light source (not shown) is passed though a polarising filter 2, (hereinafter referred to as " the polariser "), an iris 3, and a condenser 4, to illuminate a specimen on the slide 5, the light rays then passing through the microscope objective 6 and an analyser 7 which takes the form of a polarising filter having a direction of polarisation at right angles to that of polariser 2.

In use the analyser 7 can be rotated about the optical axis of the instrument and ideally, when there is no specimen on the slide 5, adjustment of analyser 7 enables the light source to be completely blotted out when the direction of polarisation of 7 is exactly opposite to that of 2.

In practice, however, when large apertures are used, some rotation of the plane of polarisation is caused by the various intermediate optical elements, principally condenser 4 and objective 6. This rotation of the plane of polarisation occurs in the oblique quadrants as a result of the greater loss by reflection of the tangential as compared with the radial components of the light. When this occurs it is not possible to obtain complete extinction of the light beam passing to the eyepiece (not shown) of the microscope. This can be more readily appreciated by means of the diagrams on the right of Figure 1 in which 8 shows the polarisation of the light beam emerging from polariser 2 and diagram 9 shows the distortion caused by the rotation of the plane of polarisation in the oblique quadrants, as described above. With the analyser 7 in the position which should ideally cause complete obliteration of the light beam, only a cross in the middle of the objective aperture can be extinguished. This is illustrated in diagram 10. By adjustment of the analyser 7 different parts of the beam can be extinguished but never the whole of it.

The present invention comprises a microscope of the type described in which one or more optical elements are introduced in the path of the light beam between the polariser and the analyser which produce rotation of the plane of polarisation equal and opposite to the rotation brought about in the manner described above by the other elements of the optical system between the polariser and the analyser.

Where the said element or elements are placed in a part of the light beam where the rays are convergent or divergent the said element or elements may comprise a plane parallel plate of birefringent material but where the said elements are placed in a part of the light beam where the rays are substantially parallel the element or elements should comprise components of optically active or birefringent material with cylindrical or toroidal, as well as plane or spherical surfaces.

Figure 2 illustrates a practical embodiment of the invention. The light from a light source (not shown) first passes through a field

iris 11 before passing through the polariser 2. On emerging from polariser 2 the light passes through a slab of birefringent material 12, the effect of which is to produce elliptical polarisation in the oblique quadrants in the manner shown in diagram 13. The slab 12 should be of uniaxial birefringent material with the optical axis parallel with the optical axis of the microscope. A quarter-wave plate 14 is now placed in the path of the beam and converts the polarisation pattern 13 to the pattern shown in diagram 15 by conversion of the elliptical polarisation to rotation of polarisation and it will be noted that this is complementary to diagram 9 in Figure 1, so that when the beam has further been distorted by passing through elements 4, 5 and 6, the beam is restored to plane polarisation in the same direction over its whole area, as illustrated in diagram 16 which resembles diagram 8.

It is then possible by adjustment of analyser 7 to extinguish the whole of the light beam as indicated by diagram 17.

In another embodiment of the invention shown in Figure 3 the effect obtained by items 12 and 14 of Figure 2 is obtained by the use of a single half-wave plate 18. This half-wave plate must be composed of a biaxial material with a considerably different refractive index in the direction parallel to the optical axis of the instrument from that in the other two directions. Mica is a suitable material of this kind and should be used with the plane of cleavage normal to the optical axis of the instrument.

To achieve the same effect as the embodiment described in relation to Figure 2, however, it may be necessary for the angle of divergence of the light emerging from the field iris 11 to be greater than in the case of the Figure 2 embodiment, but this presents no particular difficulty.

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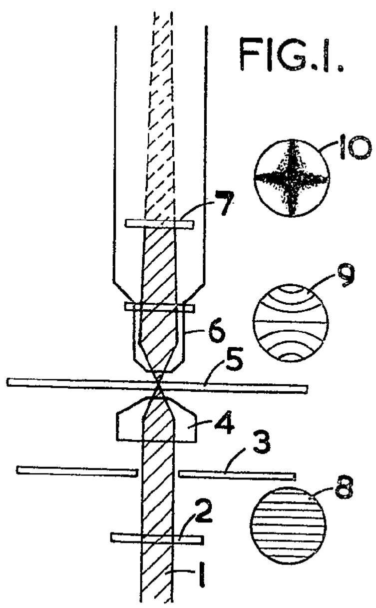

FIG.1.

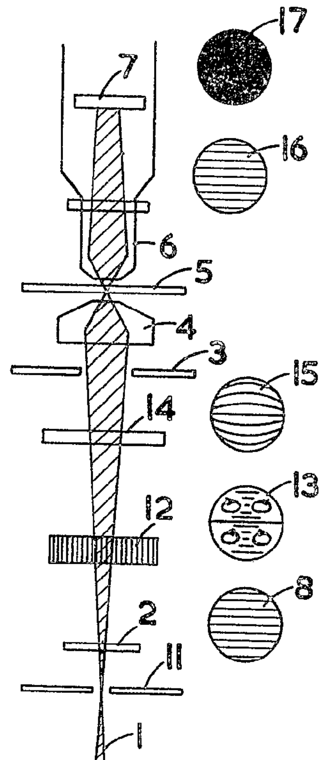

FIG.2.

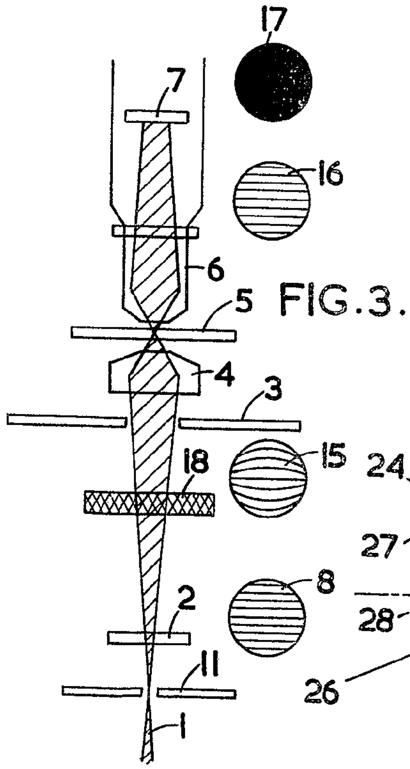

FIG.3.

FIG.4.